

# Carbon and nitrogen dynamics in early stages of forest litter decomposition as affected by nitrogen addition

DENG Xiao-wen<sup>1,3</sup>, LIU Ying<sup>2</sup>, HAN Shi-jie<sup>3</sup>

<sup>1</sup> Tianjin Academy of Environmental Sciences, Tianjin 300191, P. R. China

<sup>2</sup> College of Light Industry and Food Sciences, South China University of Technology, Guangzhou 510640, P. R. China

<sup>3</sup> Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China

**Abstract:** The effects of nitrogen (N) availability and tree species on the dynamics of carbon and nitrogen at early stage of decomposition of forest litter were studied in a 13-week laboratory incubation experiment. Fresh litter samples including needle litter (*Pinus koraiensis*) and two types of broadleaf litters (*Quercus mongolica* and *Tilia amurensis*) were collected from a broadleaf-korean pine mixed forest in the northern slope of Changbai Mountain (China). Different doses of N (equal to 0, 30 and 50 kg·ha<sup>-1</sup>·yr<sup>-1</sup>, respectively, as NH<sub>4</sub>NO<sub>3</sub>) were added to litter during the experiment period. The litter decomposition rate expressed as mass loss and respiration rate increased significantly with increasing N availability. The mass loss and cumulative CO<sub>2</sub>-C emission were higher in leaf litter compared to that in needle litter. The dissolved organic Carbon (DOC) concentrations in litter leachate varied widely between the species, but were not greatly affected by N treatments. Regardless of the N addition rate, both N treatments and species had no significant effect on dissolved organic N (DON) concentrations in litter leachate. About 52–78% of added N was retained in the litter. The percentage of N retention was positively correlated ( $R^2=0.91$ ,  $p<0.05$ ) with the litter mass loss. This suggested that a forest floor with easily decomposed litter might have higher potential N sink strength than that with more slowly decomposed litter.

**Keywords:** carbon and nitrogen dynamics; decomposition; forest litter; nitrogen addition

## Introduction

Increases in anthropogenic atmospheric nitrogen (N) deposition over the past several decades have led to concern about its effect on biogeochemical cycling in forest ecosystems. Although forests are often N-limited (Vitousek and Howarth 1991; Aber 1992), assimilation of N by vegetation is small relative to the quantity of N retained by soil, especially in organic horizons (Nadelhoffer et al. 2004). Such a great retention of N may affect carbon (C) and N dynamics in forest soils.

Litter is a top layer in forest soil profile. The ecological impact of C and N dynamics in the litter layer is considerable in forest ecosystems. Fresh litter can uptake or immobilize N because it is relatively rich in C and poor in N. Thus, the litter layer can become a significant sink for N. As decomposition proceeds, min-

eralization predominates over immobilization, then, the litter gradually releases N and becomes a source for N. In addition, the dissolved organic C (DOC) and dissolved organic N (DON) originated from litter decomposition is the most important source of dissolved organic matter in forest soils (Qualls and Haines 1991; Park et al. 2002), which is considered to be an energy and nutrient source of microbial metabolism (Magill and Aber 2000). Furthermore, litter CO<sub>2</sub> respiration can account for 10%–30% of total soil CO<sub>2</sub> flux, and it is important for the balance of forest C budgets (Buchmann 2000; Lin et al. 2004).

Numerous studies have examined C and N dynamics of forest litter under ambient environmental conditions (Melillo et al. 1982; McLaugherty et al. 1985; Blair 1988; Moore et al. 1999; Limpens and Berendse 2003; Prescott et al. 2004) or under laboratory conditions (Taylor et al. 1989; Park et al. 2002). These experiments confirm that C quality and N content of the litter control both mass loss and N dynamics of decomposition. However, very few experiments have been done on micro-scale changes in C and N cycling under elevated N concentrations. A stimulatory effect of N deposition on litter decomposition in the early stages was reported (Vestgarden 2001; Berg and Matzner 1997) and both internal N and external N significantly increased the CO<sub>2</sub> emission and mass loss. In contrast to that, Hobbie (2000) found N deposition would have small effects on litter decomposition in ecosystems characterized by high-lignin litter. Currently, the effect of N deposition on litter DOC production is not fully understood. Alison and Aber (2000) found that there

Foundation project: This work was supported by the Knowledge Innovation Project of the Chinese Academy of Sciences (KZCX2-YW-416) and the National Natural Science Foundation (90411020)

Received: 2008-10-22; Accepted: 2008-11-25

© Northeast Forestry University and Springer-Verlag 2009

The online version is available at <http://www.springerlink.com>

Biography: DENG Xiao-wen (1976- ), male, Ph.D, Tianjin Academy of Environmental Sciences, Tianjin 300191, P.R. China.

E-mail: [liuyingamy@163.com](mailto:liuyingamy@163.com)

Responsible editor: Hu Yanbo

was no net change of DOC export from leaf litter (seven species) affected by N addition in a laboratory incubation experiment. While, McDowell (1998) observed little change in DOC concentrations (10–30% increase, not statistically significant) associated with elevated N inputs. Aber (1992) hypothesized that increased utilization of DOC due to increased N input would reduce the DOC leaching. It is unclear whether DON leaching will increase with N deposition or not. An increased DON leaching was observed after addition of N in litter (Alison and Aber 2000; Pregitzer et al. 2004), while Vestgarden (2001) reported addition of N to pine litter samples did not affect the DON leaching from these samples. Nitrogen often shows immobilization in early stage of litter decomposition (Berg and Ekbohm 1983; Gallardo and Merino 1992). Still, it is unclear whether the litter N immobilization associates with the litter quality or the N availability.

The aim of this experiment was to study the effects of N deposition on C and N dynamics during the early stage of decomposition of forest litter. Our objectives were to: 1) determine the effects of N addition by comparing N treated litters with their un-treated counterparts and of N concentration by comparing the effect of two different N additions; 2) determine the effect of litter quality by comparing three types of litter.

## Materials and methods

### Field collection

In September 2005, fresh litter was collected from a 200-year-old broadleaf and Korean pine mixed forest in the northern slope of Changbai Mountain (47°24'N, 128°28'E) National Nature Reserve in Northeast China. Tree density of the site was 437 trees·ha<sup>-1</sup>. Dominant tree species in the site are *Pinus koraiensis* (PK), which occupies 30% of the area, followed by 24% *Tilia amurensis* (TA) and 20% *Acer mono*. Annual litter production for the selected site is about 4000 kg·ha<sup>-1</sup>·a<sup>-1</sup>.

Litter of *Pinus koraiensis*, *Quercus mongolica* (QM) and *Tilia amurensis* were used as materials. Fresh litter was collected in circular traps devised by Hughes et al. (1987). Twelve traps were randomly installed at selected site and harvested at weekly intervals. Litter was gathered in paper bags, air dried at room temperature and separated by species.

### Experimental design and treatment

Glass columns (13 cm long × 2.6 cm dia.) were used as sample tubes. A 5-g acid-washed glass wool (soaked in 10% HCl for 24 h then DI rinsed) laid on the bottom of column was used to prevent material escaping from the column. After cutting litter into 1 cm × 1 cm (leaf litter) size or 1 cm lengths (needle litter), the air-dried litter (equivalent to 2 g dry weight) was placed in each column. The litter was then inoculated with 1.5 mL of a 10 times diluted forest soil solution. The soil used for this purpose was sampled from the forest floor of selected sites. At the same time, 1-mL nutrient solution (4.0 g·L<sup>-1</sup> KH<sub>2</sub>PO<sub>4</sub>, 0.4 g·L<sup>-1</sup> CaCl<sub>2</sub>·2H<sub>2</sub>O, and 0.8 g·L<sup>-1</sup> MgSO<sub>4</sub>·7H<sub>2</sub>O) was also added to the columns. Each treatment was replicated five times. Columns were lined up on

trays covered with wetted blotting paper (replaced every day) to keep constant moisture content. The trays were then inserted in incubators for 13-week incubation. Air temperature inside the incubator was kept between 20°C and 21°C.

The experiment included three treatments: control, low N and high N (correspond to 0, 30 kg·ha<sup>-1</sup>·a<sup>-1</sup> and 50 kg·ha<sup>-1</sup>·a<sup>-1</sup>, respectively). The total amount of N addition was about 0, 4.41 mg·g<sup>-1</sup> dry litter and 7.35 mg·g<sup>-1</sup> dry litter, respectively. Nitrogen was added as solutions of NH<sub>4</sub>NO<sub>3</sub> every two weeks.

All samples were leached with 50 mL artificial solution every two weeks. The composition of the solution was adjusted to the average chemical composition of throughfall at selected sites with 42 mg·L<sup>-1</sup> KH<sub>2</sub>PO<sub>4</sub>, 2 mg·L<sup>-1</sup> Na<sub>2</sub>SO<sub>4</sub>, 23 mg·L<sup>-1</sup> CaCl<sub>2</sub> and 9 mg·L<sup>-1</sup> MgSO<sub>4</sub>·7H<sub>2</sub>O. The percolated solution was collected and filtered using 0.45 mm Millipore filters. Dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) in the solution were analyzed by a TOC/TN analyser (multi N/C 3000, Analytik, Jena, Germany). DIN (NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>) was analyzed with flow injection analysis (FIA star 5000 analyser, Tecator, Höganäs, Sweden). At the end of the incubation, the litter was extracted with 2 M KCl, and the DIN in extracts was measured using the method mentioned earlier. The extracted litter was then thoroughly washed with distilled water, dried at 105°C and weighed for calculation of the mass loss. Both the initial and the final decomposed samples were analyzed for total N, total C and lignin. Total N and total C were analyzed on a Vario EL-III elemental analyzer (Elementar, Germany). Lignin was measured with an acetyl bromide digestion technique (Iiyama and Wallis 1990).

### Calculations and statistics

Dissolved organic N was calculated by subtracting DIN from TDN. For DOC, DON and DIN, cumulative values were calculated as the sum of all the single observations for each column. The cumulative CO<sub>2</sub>-C emissions were calculated by subtracting the cumulative DOC losses and final C content from initial C content for each sample. Net N retention rate (only calculated on samples with N addition) was calculated as the ratio of the amount of net N retention to added N. The amount of net N retention was determined by the difference between initial and final N content of litter.

A two-way analysis of variance (ANOVA) was used to test for significant differences ( $P \leq 0.05$ ) among treatments and species. A t-test was used to test for significant differences ( $P \leq 0.05$ ) between the means of litter characteristics. The relationships between different processes were determined by calculating Pearson correlation coefficients. All statistical analyses were performed using SAS (SAS Institute Inc. 1997).

## Results and discussion

### C and N budget

The mass loss after 13 weeks of decomposition varied from 13% to 30% of the initial mass for species and treatments (Table 1). N

addition significantly increased the mass loss for all three species ( $P<0.05$ ). The values of mass loss followed the order high N>Low N>control for certain species, but the difference between two N treatments for PK was small. The mass loss varied considerably between the three species ( $P<0.05$ ). Mass loss of the leaf litter (TA, QM) was greater than that of the needle litter (PK). The differences in mass loss were small between two leaf litters. The average value of mass loss was higher in TA than in QM under N treatments.

The amounts of cumulative DOC leaching varied between 3.9

mg·g<sup>-1</sup> and 9.2 mg·g<sup>-1</sup> dry litter for the different species (Table 1). No significant difference in cumulative DOC leaching was found under N treatments when all the species were taken into account. However, the species varied considerably in the pattern of DOC release under N treatments. A positive relationship between cumulative DOC leaching and N additions was found in TA. In contrast, the cumulative DOC leaching decreased with increasing N addition in QM. No relationship was observed between the cumulative DOC leaching and N additions in PK (Table 1).

**Table 1. Carbon (C) and nitrogen (N) budget for each species by nitrogen treatment. All values are in units of mg·g<sup>-1</sup> dry litter unless otherwise noted**

Species	Initial litter C (S.E)	Final litter C (S.E)	DOC-C loss (S.E)	CO <sub>2</sub> -C loss	Initial litter N (S.E)	Final Litter N (S.E)	Added N	N immobilization (%)	Initial litter lignin (S.E)	Final litter Lignin (S.E)	Mass loss (S.E)
<i>Pinus koraiensis</i> (PK)											
Control	533 (2)	473 (7)	4.8 (0.7)	55.2	4.0 (0.1)	3.7 (0.2)	0	-	256 (8)	294 (11)	127.2 (7.8)
Low N	533 (2)	452 (10)	4.1 (0.1)	76.9	4.0 (0.1)	6.5 (0.4)	4.4	56.8	256 (8)	287 (17)	172.5 (9.0)
High N	533 (2)	442 (12)	5.0 (0.3)	86	4.0 (0.1)	7.9 (0.9)	7.4	52.7	256 (8)	309 (9)	187.2 (15.2)
<i>Quercus mongolica</i>											
Control	463 (4)	366 (8)	9.3 (1.3)	87.7	11.4 (0.1)	10.8 (0.3)	0	-	241 (16)	276 (12)	253.5 (11)
Low N	463 (4)	349 (13)	7.1 (0.5)	106.9	11.4 (0.1)	14.2 (0.6)	4.4	63.6	241 (16)	269 (16)	271.0 (6.5)
High N	463 (4)	318 (9)	6.7 (0.4)	138.3	11.4 (0.1)	16.5 (0.8)	7.4	69.3	241 (16)	271 (11)	285.5 (4.5)
<i>Tilia amurensis</i>											
Control	438 (2)	340 (18)	7.3 (0.2)	90.7	8.9 (0.6)	8.5 (0.2)	0	-	229 (7)	257 (13)	248.8 (4.3)
Low N	438 (2)	311 (11)	8.5 (0.2)	118.5	8.9 (0.6)	12.3 (0.7)	4.4	77.2	229 (7)	247 (10)	287.7 (9.7)
High N	438 (2)	274 (14)	8.7 (0.3)	155.3	8.9 (0.6)	14.7 (0.6)	7.4	78.4	229 (7)	243 (15)	306.3 (9.8)

The cumulative C mineralization (as CO<sub>2</sub>-C emission) and N retention rate were calculated based on the chemical characteristics of litter samples before and after incubation. Total CO<sub>2</sub>-C emitted during the incubation ranged from 55 mg·g<sup>-1</sup> to 155 mg·g<sup>-1</sup> dry litter for the different N treatments and species (Table 1). Significant effects of N additions were found when all the measurements were taken into account ( $P<0.05$ ). For all species, the cumulative CO<sub>2</sub>-C increased with increasing N addition, however, the emission did not increase much when more N was applied for PK. Significant differences in cumulative CO<sub>2</sub>-C emission were found among three species ( $P<0.05$ ). Under the same N availability level, the values of cumulative CO<sub>2</sub>-C emission followed the order TA>QM>PK. The differences in cumulative CO<sub>2</sub>-C emission between TA and QM were relatively smaller as compared with the differences between PK and QM. For all the species and treatments, CO<sub>2</sub>-C emission constituted (92±3)% of the total C loss, indicating that CO<sub>2</sub>-C emission is the major way of C loss from forest litter.

Net N retention increased in response to N additions for all species. However, the percentages of N retention were similar under the high- or low-N treatments for each species (Table 1). A positive correlation was found between the percentage of N retention and the litter mass loss ( $R^2=0.91$ ,  $p<0.05$ ), showing greater N retention ability for the easily decomposed litter.

Measurements of mass loss and CO<sub>2</sub> emission represent two independent measures of the decomposition rate of litters. The

11%–36% mass loss of the initial litter mass after 13 weeks under laboratory conditions is approximately equal to the mass loss during the first year in a litterbag study of the same materials (Li et al. 2006). In the present study, the cumulative CO<sub>2</sub> emission showed a strong positive correlation ( $R^2=0.90$ ,  $p<0.05$ ) with mass loss.

The mass loss (cumulative CO<sub>2</sub>-C emission) was accelerated by N additions for all species, indicating that the increase of N availability speeds the decomposition. Such a stimulatory effect of N input on decomposition rate in early decomposition stages has been found in other studies (Adams and Cornforth 1973; Hohmann and Neely 1993; Vestgarden 2001). According to Berg and Matzner (1997), the main decomposed substances were soluble and nonlignified holocellulose in this phase. Raised concentrations of N stimulated the microbial decomposition rate of these substances. In present study, lignin content of initial samples did not vary significantly from the final samples. The final values of lignin content among treatments were also similar for certain species (Table 2). These provided indirect evidence that nonlignified matter was the main decomposed substance in our short duration laboratory incubation. The mass loss (cumulative CO<sub>2</sub>-C emission) was higher in high N than in low N for all three species, but the difference was small for PK. This demonstrates that there exists an upper limit for a positive effect of N addition. A few other laboratory studies have dealt with the effects of different doses of N addition on early stages of litter decomposi-

tion. An upper limit for a positive effect of N addition was also found in an N addition experiment on litter of Scots pine (Vestgarden 2001), however no upper limit was found for QM and TA in this study. This is because the leaf litter generally decomposes faster and the amount of N required is larger than that of the needle litter. Thus, the N upper limit for QM and TA may be beyond the dose of N we added in the present study.

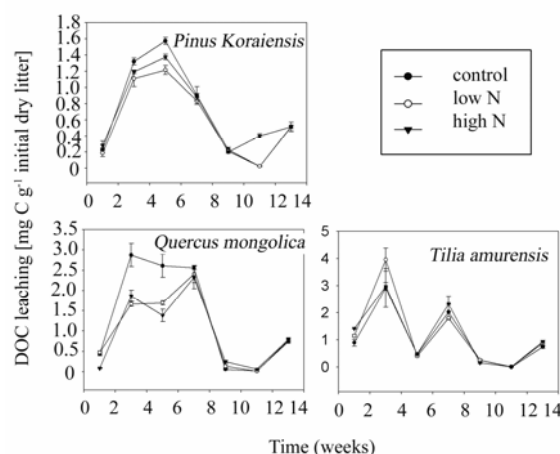
Significant differences in mass loss (cumulative  $\text{CO}_2$ -C emission) were found among the species. Mass loss (cumulative  $\text{CO}_2$ -C emission) of the leaf litters was greater than that of the needle litter due to significantly higher N concentration and lower in lignin concentration in TA and QM than in PK ( $P < 0.05$ ). Similar results were found in other studies. Cornelissen (1996) found that leaves of deciduous species decomposed twice as fast as those of evergreens under controlled conditions. Flanagan and Van Cleve (1983) found that birch litter decomposed six times faster than spruce litter. The average mass loss (cumulative  $\text{CO}_2$ -C emission) was slightly higher in TA than in QM under N treatments in the present study. This may be due to higher lignin content in QM than in TA ( $P < 0.05$ ). According to Hobbie (2000), litter C quality and N availability interact to control rates of litter decomposition. Fresh litter may contain insufficient N to support microbial use in early stages of decomposition (Staaf and Berg 1981; Berg and Matzner 1997) and N concentration may control decomposition rate in this phase. However, under N treatments, the requirement of N is met and C quality may become a constraining factor on litter decomposition.

#### DOC leaching

The individual observation of DOC leaching on two-week basis also showed an irregular behavior over time for the three species (Fig. 1). Significant differences in cumulative DOC leaching were found among three species ( $p < 0.05$ ). PK showed the lowest value of cumulative DOC leaching (Table 1).

DOC leaching is another important avenue of C release from decomposing forest litter. Cumulative DOC leaching accounted for 5%–10% of C loss in the present study. No significant cumulative DOC leaching was found under N treatments when all the species were taken into account. However, different species varied considerably in the patterns of DOC released under N treatments. The effect of N availability on DOC leaching can be explained by two different mechanisms. Guggenberger (1992) and Zech et al. (1994) assumed that N availability could affect DOC leaching by stimulating the microbial activity and hence increasing mineralization of organic matter, which in turn can increase DOC production. While, Aber (1992) hypothesized that increased utilization of DOC due to increased N input would reduce the DOC leaching. Vestgarden (2001) proposed that possible changes in DOC leaching due to N availability would depend on balance of the two contrasting mechanisms. In the present study, individual observations of DOC leaching under different N treatments varied greatly over the incubation time (Fig. 1). This suggests that the balance of production and utilization of DOC due to N addition is unstable in the early stages of forest litter decomposition. The effect of DOC leaching due to N addi-

tion is uncertain in early stages of litter decomposition for different N supply, incubation time and species. Significant differences in cumulative DOC leaching were found among the three species, indicating that DOC leaching was controlled by litter quality. According to Pregitzer et al. (2004), fresh litterfall is the biggest contribution to annual DOC production. Therefore, the DOC concentration of the soil solution would greatly depend on forest or community types. Increased N status in the decomposing litter did not significantly affect DOC leaching.



**Fig. 1** Time series graphs of weekly dissolved organic carbon (DOC-C,  $\text{mg}\cdot\text{g}^{-1}$  initial dry litter) leached from decomposing litter over the 13 weeks. Each point represents the mean of five replicate columns.

#### DON and DIN leaching

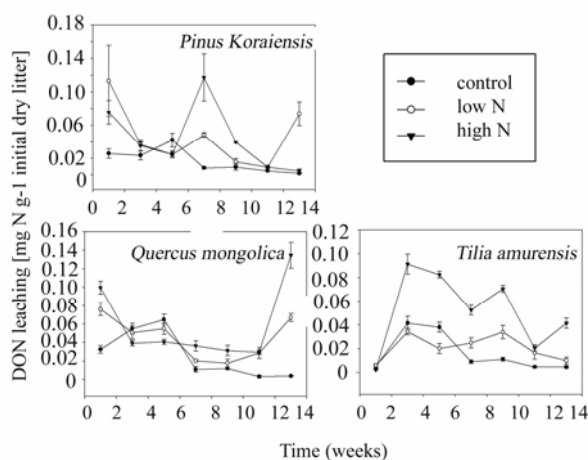
The leaching of cumulative DON-N varied from  $0.12 \text{ mg}\cdot\text{g}^{-1}$  to  $0.41 \text{ mg}\cdot\text{g}^{-1}$  dry litter for species and treatments. Neither N treatments nor species significantly affected the cumulative DON leaching, although DON in leachate from N treated samples was consistently higher than that of the controls (Fig. 2, Fig. 3). DON accounted for 75% to 90% of N in leachate of control samples, indicating that DON was the major source of N transport from the litter where no N was added. No significant correlation between DOC and DON was observed.

The leaching of DIN responded significantly to the amount of N addition ( $R^2 = 0.85$ ,  $p < 0.05$ ). Cumulative values varied from  $0.02$  to  $2.50 \text{ mg N g}^{-1}$  dry litter for species and treatments (Fig. 3). About 65%–90% of the total N loss during the experiment was in the form of DIN where N was added. Only small amounts of the DIN were detected in control samples, indicating that most DIN probably originated from the added N passed directly through the litter.

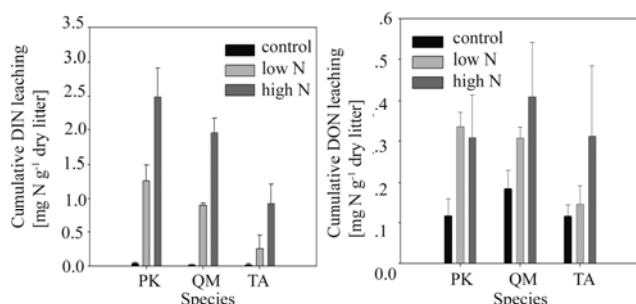
DON is an important N resource for the bacteria and phytoplankton in freshwater, soil solution and marine environments. Recent researches have shown that some forms of DON could be uptaken by plants without relying on microbial mineralization (Neff et al. 2003). In the present study, cumulative DON leaching accounted for 75%–90% of total N loss in control samples.



These values are lower than those presented by Magill and Aber (2000) who concludes that up to 93% of total N loss was released as DON.



**Fig.2** Time series graphs of weekly dissolved organic nitrogen (DON-N,  $\text{mg}\cdot\text{g}^{-1}$  initial dry litter) leached from decomposing litter over the 13 weeks. Each point represents the mean of five replicate columns.



**Fig.3** Cumulative DIN ( $\text{NH}_4^+$  and  $\text{NO}_3^-$ ) and DON (dissolved organic nitrogen) leaching ( $\text{mg}\cdot\text{g}^{-1}$  dry litter) for *Pinus koraiensis*(PK), *Quercus mongolica*(QM); *Tilia amurensis*(TA) during 13-week experiment period. Error bars indicate standard deviations,  $n=5$ .

In the present study, neither N treatments nor species significantly affected DON leaching, while DON in leachate from N treated samples was always higher than that from controls (Fig. 2). This suggests that a portion of the added N could be converted to DON. The mechanisms responsible for generation of DON include a complex mix of biotic and abiotic processes (Neff et al. 2003), either directly from microbial turnover (Seely and Lajtha 1997) and indirectly through microbial generation of extracellular enzymes (Trasar-Cepeda et al. 2000), or formed by the reaction of nitrite with dissolved organic matter (Perakis and Hedin 2001; Davidson et al. 2003). Thus, the production of DON may be significantly higher in N treated litter (higher microbial activity and  $\text{NO}_3^-$ -N) than in control. However, according to Cleveland et al. (2004), the DON leached from litter also appears to be highly labile. Part of the DON might be mineralized into DIN and leached from the columns or was immobilized by litter in a short time. Therefore, as with the leaching of DOC, the pos-

sible change in the DON leaching due to N availability may depend on the balance of production and utilization process. Individual observations of DON leaching under different N treatments showed great fluctuation over the incubation time (Table 2), suggesting the instability of DON change due to N availability. Such a great fluctuation of DON leaching under different N treatments was also observed in another experiment (Vestgarden 2001). In the present study, increased N availability did decrease the leachate DOC-to-DON ratio, indicating dissolved organic matter rich in N was input to the forest floor under N treatments.

In absolute value, the cumulative DIN leaching increased when the dose of input N increased in the present experiment. DIN leaching was the major source of N loss where N was added. However, the DIN leaching from the control samples indicates that a net N mineralization occurred. The cumulative N loss, including DIN and DON leaching, varied from 14% to 41% of added N in the present experiment. Thus about 59%–86% of the added N was retained in the system. This is slightly higher than the net N retention rate calculated by the chemical characteristics of litter samples before and after incubation (52%–78%). Such a small difference might be due to overlooking  $\text{N}_2\text{O}$  emissions. Net N immobilization in litter decomposition processes has been reported in other studies (Berg and Ekbohm 1983; Gallardo and Merino 1992). Microbial uptake of N is one possible mechanism (Fog 1988). It is also possible that N is retained in the litter by its incorporation into chemically inert compounds (Berg and Matzner 1997).

In absolute values, the amount of net N immobilization increased when the dose of external N increased. However, the percentage of N immobilization under our two doses of N addition was similar for certain species. This suggests that the ability to immobilize N would depend on the litter quality under a suitable gradient of N input. A positive correlation was found between percentage of N immobilization and litter mass loss (Fig. 6), showing greater N immobilization ability for the easily decomposed litter. A series of  $^{15}\text{N}$  tracer studies demonstrate that soil was the strongest sink for N addition and Oi (recent litter) and Oa (“humus” layers) accounted for more than two-thirds of tracer recoveries from soil profiles (Nadelhoffer et al. 2004; Nadelhoffer et al. 1999). The present study also demonstrated the potential importance of the litter in intercepting the added N in a forest ecosystem. The generally higher ratios of N retention for easily decomposed litter suggests that the forest floor with easily decomposed litters may have higher potential to be an N sink than that with the slowly decomposed litters.

## Conclusion

According to the results and discussions above, increased N status due to atmospheric N deposition or fertilization may result in considerable changes on litter decomposition progress. However, further validation of these effects under field conditions and studies elucidating the mechanisms responsible are required.

## Acknowledgements

We thank Xu Hao for litter collection and Liu Guoliang for

checking the English language of this paper.

## References

- Adams SN, Cornforth IS. 1973. Some short-term effects of lime and fertilizers on a Sitka spruce plantation. II. Laboratory studies on litter decomposition and nitrogen mineralization. *Forestry*, **46**: 39–47.
- Aber JD. 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. *Tree*, **7**: 220–223.
- Berg B, Ekbohm G. 1983. Nitrogen immobilization in decomposing needle litter at variable carbon-nitrogen ratios. *Ecology*, **64**: 63–67.
- Berg B, Matzner E. 1997. Effect of N deposition on decomposition of plant litter and soil organic matter in forest systems. *Environmental Reviews*, **5**: 1–25.
- Blair JM. 1988. Nitrogen, sulfur and phosphorus dynamics in decomposing deciduous leaf litter in the Southern Appalachians. *Soil Biology and Biochemistry*, **20**: 693–701.
- Buchmann N. 2000. Biotic and abiotic factors controlling soil respiration rates in *Picea abies* stands. *Soil Biology and Biochemistry*, **32**: 1625–1635.
- Cleveland CC, Neff JC, Townsend AR, Hood E. 2004. Composition, dynamics, and fate of leached dissolved organic matter in terrestrial ecosystems: Results from a decomposition experiment. *Ecosystems*, **7**: 275–285.
- Cornelissen JHC. 1996. An experimental comparison of leaf decomposition rates in a wide variety of temperate plant species and types. *Journal of Ecology*, **84**: 573–582.
- Davidson EA, Chorover J, Dail BD. 2003. A mechanism of abiotic immobilization of nitrate in forest ecosystems: the ferrous wheel hypothesis. *Global Change Biology*, **9**: 228–36.
- Flanagan PW, Van Cleve K. 1983. Nutrient cycling in relation to decomposition and organic-matter quality in taiga ecosystems. *Canadian Journal of Forest Research*, **13**: 795–817.
- Fog K. 1988. The effect of added nitrogen on the rate of decomposition of organic matter. *Biological Reviews*, **63**: 433–462.
- Gallardo A, Merino J. 1992. Nitrogen immobilization in leaf litter at two Mediterranean ecosystems of SW Spain. *Biogeochemistry*, **15**: 213–228.
- Guggenberger G. 1992. Eigenschaften und Dynamik gelöster organischer Substanzen (DOM) auf unterschiedlich immissionsbelasteten Fichtenstandorten. *Bayreuther Bodenkundliche Berichte*, **26**: 1–164.
- Hobbie SE. 2000. Interactions between litter lignin and soil nitrogen availability during leaf litter decomposition in a Hawaiian montane forest. *Ecosystems*, **3**: 484–494.
- Hohmann J, Neely RK. 1993. Decomposition of *Sparangium eurycarpum* under controlled pH and nitrogen regimes. *Aquatic Botany*, **46**: 17–33.
- Hughes JW, Fahey TJ, Browne B. 1987. A better seed and litter trap. *Canadian Journal of Forest Research*, **17**: 1623–1624.
- Iiyama K, Wallis AFA. 1990. Determination of lignin in herbaceous plants by an improved acetyl bromide procedure. *Journal of the Science of Food and Agriculture*, **51**: 145–161.
- Li Xuefeng, Han Shijie, Guo Zhongling, Zhen Xingbo, Song Guozheng, Li Kaixue. 2006. Decomposition of pine needles and twigs on and under the litter layer in the natural Korean pine broadleaved forests. *Journal of Beijing Forestry University*, **28** (3): 8–13.
- Limpens L, Berendse L. 2003. How litter quality affects mass loss and N loss from decomposing Sphagnum. *Oikos*, **103**: 537–547.
- Lin Lisha, Han Shijie, Wang Yuesi, Gu Zhijiang. 2004. Soil CO<sub>2</sub> flux in several typical forests of Mountain Changbai. *Chinese Journal of Ecology*, **23**(5): 42–45.
- Magill AH, Aber JD. 2000. Dissolved organic carbon and nitrogen relationships in forest litter as affected by nitrogen deposition. *Soil Biology and Biochemistry*, **32**: 603–613.
- McLaugherty CA, Pastor J, Aber JD. 1985. Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. *Ecology*, **66**(1): 266–275.
- Melillo JM, Aber JD, Muratore JF. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology*, **63**(3): 621–626.
- Moore TR, Trofymow JA, Taylor B, Prescott C, Camire C, Duschene L, Fyles J, Kozak L, Kranabetter M, Morrison I, Siltanen M, Smith S, Titus B, Visser S, Wein R, Zoltai S. 1999. Litter decomposition rates in Canadian forests. *Global Change Biology*, **5**: 75–82.
- Nadelhoffer KJ, Colman BP, Currie WS, Magill AH, Aber JD. 2004. Decadal scale fates of <sup>15</sup>N tracers added to oak and pine stands under ambient and elevated N inputs at the Harvard Forest (USA). *Forest Ecology and Management*, **196**: 89–107.
- Nadelhoffer KJ, Emmett BA, Gundersen P, Kjonass OJ, Koopmans CJ, Schleppi P, Tietema A, Wright RF. 1999. Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. *Nature*, **398**: 145–148.
- Neff JC, Chapin FS, Vitousek PM. 2003. Breaks in the cycle: dissolved organic nitrogen in terrestrial ecosystems. *Frontiers in Ecology and Environment*, **1**: 205–211.
- Park JH, Kalbitz K, Matzner E. 2002. Resource control on the production of dissolved organic C and nitrogen in a deciduous forest floor. *Soil Biology and Biochemistry*, **34**: 813–822.
- Perakis SS, Hedin LO. 2001. Fluxes and fates of nitrogen in soil of an unpolluted old-growth temperate forest, southern Chile. *Ecology*, **82**: 2245–2260.
- Pregitzer KS, Zak DR, Burton AJ, Ashby JA, MacDonald NW. 2004. Chronic nitrate additions dramatically increase the export of carbon and nitrogen from northern hardwood ecosystems. *Biogeochemistry*, **68**: 179–197.
- Prescott CE, Vesterdal L, Preston CM, Simard SW. 2004. Influence of initial chemistry on decomposition of foliar litter in contrasting forest types in British Columbia. *Canadian Journal of Forest Research*, **34**: 1714–1729.
- Qualls RG, Haines BL. 1991. Geochemistry of dissolved organic nutrients in water percolating through a forest ecosystem. *Soil Science Society of America Journal*, **55**: 1112–1123.
- SAS Institute Inc. 1997. Procedures guide, Release 6.12. Cary, NC, USA.
- Seely B, Lajtha K. 1997. Application of a <sup>15</sup>N tracer to simulate and track the fate of atmospherically-deposited N in the coastal forests of the Waquoit Bay Watershed, Cape Cod, MA. *Oecologia*, **112**: 393–402.
- Staaf H, Berg B. 1982. Accumulation and release of plant nutrients in decomposing Scots pine needle litter: long-term decomposition in a Scots pine forest II. *Canadian Journal of Botany*, **60**: 1561–1568.
- Taylor BR, Parkinson D, Parsons WJ. 1989. Nitrogen and lignin content as predictors of litter decay rates: a microcosm test. *Ecology*, **70** (1): 97–104.
- Trasar-Cepeda C, Leirós MC, Gil-Sotres F. 2000. Biochemical properties of acid soils under climate vegetation (Atlantic oak wood) in an area of the European temperate humid zone (Galicia, NW Spain): specific parameters. *Soil Biology and Biochemistry*, **32**: 747–755.
- Vestgarden LS. 2001. Carbon and nitrogen turnover in the early stage of Scots pine (*Pinus sylvestris* L.) needle litter decomposition: effects of internal and external nitrogen. *Soil Biology Biochemistry*, **33**: 465–474.
- Vitousek PM, Howarth RW. 1991. Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry*, **13**: 87–115.
- Zech W, Guggenberger G, Schulten HR. 1994. Budgets and chemistry of dissolved organic carbon in forest soils: effects of anthropogenic soil acidification. *Science of the Total Environment*, **152**: 49–62.